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From Research to Action in the Classroom: Encouraging Broad Thinking in Engineering Design with Significant Learning Experiences*

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The National Academy of Engineering (NAE) has argued that an "Engineer of 2020" should be able to situate engineering work in broader global, societal, economic, and environmental contexts. As part of the Academic Pathways Study—a longitudinal mixed-methods study of engineering students as they move into, through, and beyond undergraduate education—we asked students to react to the NAE argument and found that students did not take an especially broad view of the context of engineering. At the same time, students described significant learning experiences that suggest a framework for curriculum development to target the broader context of engineering design as a learning outcome. This framework is exemplified in a "Perspective and Art" assignment that has been carried out in several offerings of a design seminar and a Professional Teamwork and Communication Skills course. The goal of the assignment is for students to first see and then examine their own perspectives, as well as those of others. Acknowledging multiple perspectives is one step toward broadly considering the multiple contexts in which perspectives are formed.

Keywords: engineering design; context, perspective; engineering education; instructional design; art

1. Introduction

The study of how students learn engineering is particularly interesting because engineering knowledge itself is interesting. Engineering honors both objective knowledge developed through rigorous research in the sciences and the multifaceted, even chaotic, contexts in which scientific and technological knowledge are applied [1]. As the context of engineering is increasingly global and technological problems become more complex, national policymakers have been motivated to respond. More than a decade ago, the National Academy of Engineering began a conversation to envision the "Engineer of 2020" who takes a more holistic view of engineering problems and situates them in what are likely to be rather complicated and dynamic contexts [2]. Considering the context of engineering, or "contextual competence" [3] includes thinking about global [4], societal and temporal [5], natural/environmental [6], professional and economic contexts [3].

As we approach 2020—the year of our reckoning, so to speak—it is worthwhile to contemplate the extent to which the vision for the *Engineer of 2020* has come to pass, as well as the kinds of educational experiences that seem to hold promise in furthering this vision. Along the way, we took measure of where students stood, by asking graduating seniors in 2007 to respond directly to several policy statements related to context that are included in *The Engineer of 2020* [2]. Our hope was that students' interpretations of these statements would reveal not only the extent to which their undergraduate education was shaping them into the kinds of engineer envisioned by NAE policymakers, but also suggest potential individual and structural challenges that impeded their progress. As we learned, students had a somewhat narrower appreciation for and understanding of context, as compared with that envisioned for the *Engineer of 2020*. Furthermore, these students did not necessarily see the university as the place for learning about context should the need arise.

Nonetheless, we were interested in the areas of promise in undergraduate engineering education, where developing an *Engineer of 2020* who con-

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siders context more broadly could occur. To this end, we also asked the students to reflect on and describe a significant learning experience relevant to their engineering education. We think of significant learning experiences as those that engage students, in which students learn something significant and lasting, and that add value to their lives [7, 8]. Since students are the primary stakeholders in their education, we asked them to identify the qualities of significant learning that make it engaging, effective, and valuable to them. The students did identify a number of qualities that could inform educators in creating effective educational experiences, and particularly those experiences that engage students in thinking more broadly about context.

We conclude with an example of an assignment called "Perspective and Art" that has been used in multiple offerings of a design seminar and Professional Teamwork and Communication Skills class for engineering students between 2013 and 2017. The assignment is one of several that have been developed by Cindy Atman based on a broad body of research into how students consider context in engineering design [9]. It was developed specifically to engage engineering students meaningfully in thinking broadly about the context of engineering design [10]. We describe the qualities of this activity that relate to engineering in context, as well those qualities that suggest its potential as a significant learning experience. Finally, we describe the extent to which the activity is successful in furthering the goals of the NAE toward development of the *Engineer of 2020* who not only has technical knowledge and skills, but also is prepared to apply them in dynamic, complicated, and oftentimes messy contexts.

2. Developing contextual competence through design education

Engineering knowledge spans the border between the objective world of scientific thought and the multifaceted and sometimes subjective real world in which engineers practice. There should be something attractive in it for everyone. However, as Adams, et al. [11] argue, though numerous investments have been made toward engaging students in engineering education, the results in terms of engaging diverse students in engineering have been somewhat disappointing. In the same article, Stevens writes that, in his experience, "[E]ngineering education has a funny, maybe even neglectful relationship to . . . people. . . [It] is a culture in which this propensity to separate the technical and the social—the humans and the non-humans—is very deeply ingrained" [11, p. 59]. Engineering education often has been focused on the systematic application of technical knowledge to solve instrumental problems, with little space afforded to develop a well-rounded student [12-15]. This would explain why undergraduate programs have been slow to change in light of national policy that shifts the focus to include contextual competence [16].

As we might expect, an engineering learning framework that speaks little about developing contextual competence in students results in graduates who do not value nor consider context to the same extent they value and know technical competencies. For example, Sheppard et al. observed that students, regardless of whether they are beginning their studies or on the eve of graduation, assert the prominence of math and science skills over professional and interpersonal skills [17]. When asked to choose the five areas of knowledge and skills most important to engineering practice from a list based on ABET student outcomes and the *Engineer of 2020* report, almost no graduating seniors chose "global context" or "societal context," and none chose "contemporary issues" [18].

Design education increasingly is viewed as an opportunity for undergraduate engineering students to develop contextual competence [19]. Yasuhara, et al. found in a qualitative study of civil/environmental engineering students that when prompted to reflect upon their experiences, students appeared to have gained contextual competence via a broad range of educational opportunities both in and outside the classroom [5]. The challenge, the authors concluded, was in helping students honor and transfer that knowledge to future engagement in engineering design. Lattuca, et al. found that in addition to extra-curricular and co-curricular educational experiences, first-year design and capstone design courses in six engineering programs were the most likely educational experiences in which students developed contextual competence [20]. Dempere also found improvement in students' understanding of the concepts of sustainability after they disassembled products in the lab and reflected on the extent to which the original designers had considered sustainability concepts during the design of the product [21]. Neumeyer, et al. found that contextual competence of students improved after participation in product archaeology [22], a process in which students reconstruct the lifecycle of a finished product to understand the decisions that led to its development [23].

Engineering programs acknowledge design as a core competency, but design education is not always fully integrated into the curriculum. In many programs, design education is offered as a culminating capstone opportunity, or as an offering at the front and back ends of the undergraduate experience. In some landmark programs, design is integrated into the curriculum more fully, with design education included throughout the undergraduate years [19]; using such strategies as problem-based learning (PBL) [24] and case studies in engineering [25]. In these instances, there is the potential to guide students' attention to the broader context of engineering design. Some educator/researchers have also documented curricular implementations devised at least in part to focus students on the broader context of engineering design, like product archaeology [22] and using communication technology to enable internationally distributed design learning teams [26]. Regardless of how design is included in the curriculum, engineering educators hope that design experiences will lead to meaningful learning for students. Of particular interest here, the hope is that design education holds especial promise for developing contextual competence in engineering students.

3. Methods

Qualitative data are drawn from the Center for the Advancement of Engineering Education's (CAEE) Academic Pathways Study (APS), an extensive, multi-institution research project that examined how students become engineers over the trajectory of their undergraduate education and upon entry into the engineering workplace. The APS was comprised of both longitudinal and cross-sectional studies that employed multiple data collection and analysis methods. These methods included surveys, structured interviews, semi-structured interviews, engineering design tasks, academic transcripts, and exit interviews [27]. In the present analysis, we examine qualitative data from semi-structured interviews conducted with graduating seniors in Spring, 2007.

A classroom example of significant learning is drawn from the Consortium to Promote Reflection in Engineering Education (CPREE). CPREE is a collaboration among 12 institutions of higher learning that aims to "(1) identify and map practices that support reflective thinking by students; (2) produce field guides to support awareness and understanding of reflective practices; and (3) promote local use, development, and sharing of reflective practices through engagement of additional educators" [28]. The "Perspective and Art" assignment discussed in this paper asks students to think about and define the term "perspective" (or "point of view") with respect to the engineering profession. Students then find three works of art and reflect on the perspective of the artist and how the art may be experienced in different ways depending on one's own unique perspective and interaction with the artwork. Further student reflections on culture and perspective are encouraged as well, for the purpose of assisting students to consider the broader contexts in which multiple stakeholders' perspectives develop. The present analysis considers the instantiation of this activity in two design seminars and one engineering elective course. Data gathered include course artifacts and student responses to a survey about their experience with the "Perspective and Art" assignment.

3.1 Participants

The study examines how students conceptualize and talk about engineering—especially some of those aspects of engineering that may be construed as considering context. Fifteen students at one APS institution, Large Public University (LPU), participated in a semi-structured, qualitative interview in the final quarter of their senior year. LPU is a state flagship liberal arts institution with a world-class engineering college. The departments within the engineering college are selective and the programs are rigorous, particularly with respect to the development of technical skills and knowledge.

This interview represented the culmination of a longitudinal study involving these and students at other institutions that spanned their entire undergraduate careers, from Autumn, 2003 to Spring, 2007. All of the students who persisted in both engineering and the APS would be considered good students. Their interviews reflect not only academic success during the college years, but also a rich and varied education extending well beyond the classroom.

As shown in Table 1, the student participants came from seven engineering majors, resulting in a diverse cohort at least with respect to professional engineering disciplines. This small cohort also reflects the diversity of disciplines in the College of Engineering at LPU, which offers 10 engineering majors overall.

Table 1. Student Participants in APS study at LPU

Pseudonym	Major
Austin	Mechanical engineering
Brandon	Aeronautical and aerospace engineering
Drew	Chemical engineering
Elizabeth	Bioengineering
Emily	Civil engineering
Ethan	Mechanical engineering
Jesse	Aeronautical and aerospace engineering
John	Computer science & engineering
Justin	Computer science & engineering
Kara	Mechanical engineering
Lauren	Chemical engineering
Matthew	Aeronautical and aerospace engineering
Michael	Aeronautical and aerospace engineering/ Mathematics
Nicholas	Electrical engineering
Samantha	Computer Science & engineering

3.2 Data collection

During an open-ended interview conducted by one of the authors, the interviewer prompted students to describe their experiences and perceptions of many aspects of college life, including classes, extra-curricular activities, instructors and other program staff, internships and co-ops. To learn more about how students perceived engineering in context, the interviewer asked them to consider some quoted statements drawn from *The Engineer of 2020*. The interviewer provided a handout with the statements printed on it, read each of the statements, and asked several follow-on questions. The statements were:

> "We aspire to engineers in 2020 who will remain well grounded in the basics of mathematics and science, and who will expand their vision of design through a solid grounding in the humanities, social sciences, and economics" [2, p. 49].
>
> "We aspire to a future where engineers are prepared to adapt to changes in global forces and trends and to ethically assist the world in creating a balance in the standard of living for developing and developed countries alike" [2, p. 51].

The interviewer asked students to focus on "the humanities, social sciences and economics," "global forces and trends," and "ethically assisting the world" and talk about what they thought each meant, the extent to which a student had been exposed to each while in school, and the extent to which they felt prepared to employ such contextual knowledge in the future.

During the interview, the interviewer also asked students a series of questions that encouraged them to reflect upon their engineering education. The present study focuses on one of those questions: "Tell me a story about one of the most significant learning experiences you have had while you attended Large Public University." Students were encouraged to provide details about their respective experiences with several follow-up questions, including the following: "What did you learn?", "Why do you think you learned so much?", and "How do you think you will use what you learned in the future?"

These questions elicited narratives from the students that offer some insight into how they perceive themselves as engineers, as well as the conditions under which they learn best. Students chose to tell us about a range of learning experiences, from classes within their engineering programs to extracurricular activities having no direct connection to engineering topics. Students also described the qualities of these experiences that seemed to contribute to their significance for the student.

Interviews were recorded and later transcribed by a third-party transcriptionist.

3.3 Data analysis and methodology

In the present study, we take the stance that people understand their world largely through the stories they tell themselves and others [29]. Students' narratives are socially constructed, reflecting the norms of the engineering programs in which they are situated, and are sensitive to the context in which the story is told [30]. Furthermore, these narratives serve as strategic actions that maintain and reinforce the norms by which they are shaped [31]. By listening to students' narratives and identifying the underlying strategies that shape them, we can begin to understand why students behave the way they do and how they understand their engineering education [32, 33].

To make sense of the students' answers to open-ended questions, we began our analysis using a grounded theory approach to identify broadly similar narratives. Two of the authors studied transcripts of the interviews using a constant comparative method to code and re-code students' narratives using the software package ATLAS.ti. With this method, the researcher identifies "thought units" in the transcript; that is, segments of data that are focused on a particular theme or idea [31]. These thought units may be of varying size; for example, one may be a short section of conversation while another is a lengthy monologue. The purpose is not to count how many thought units the student participant has offered, but to compare and contrast these units such that they may be grouped into categories that together appear to explain something. During the first pass of coding, researchers coded every thought unit, without attempting to build a theory. Going through the transcripts a second time, the researchers compared and contrasted the various thought units as they arose, attempting to reduce the number of categories into a set of distinct themes that are theoretically broad enough to contain several thought units and so be supported by the weight of the evidence, while also being concise enough to contribute to a theory that explains some phenomenon that has emerged in the students' responses [34].

4. Findings

4.1 Students' perspectives on engineering in context

Students had mixed opinions about the relevance of the context-related knowledge areas discussed here: knowledge in other disciplines (more specifically, knowledge from economics, humanities and social sciences), global forces and trends, and ethical decision-making. While all students said that economics is important in engineering, their notions of economics were uniformly narrow. In all cases, students referred to costs or costs/benefits analysis when discussing economics and its relevance to engineering. As Justin explained, "economics always has a very direct bottom line impact on what you're designing," and added, "someone is going to pay for it, and they're going to want to know that the money is being used well." This sentiment was repeated in some form by all student respondents; as Kara quipped, "One of my professors says an engineer is a scientist on a budget. . ."

In the same narrow sense, most students thought knowledge of social sciences and humanities was important only to the extent that it enables an engineer to understand potential users of a product. Rather than seeking to "expand their vision of design" with knowledge from these other disciplines, most students related to them in terms of constraints to their designs. Most students said that knowledge from these disciplines could help them "consider how it's going to be used and what kind of people are using it," as John put it. Although it is a positive sign that engineers are thinking of the users of their products and processes, it is also true that most students did not speak to the varieties of social sciences and humanities disciplines and how knowledge of society, culture, art, and so forth, would enable them to "expand their vision of design."

To the extent that they looked beyond cost and user considerations, students asserted the difficulty of anticipating what broad contextual knowledge would be needed for a particular engineering design problem, and therefore argued that such learning could and should be deferred. For instance, Brandon described a hypothetical design scenario in which knowledge of global forces and trends would be helpful but did not necessarily recognize the potential for learning transfer, concluding, "Yeah, it's good to have some sort of knowledge about it, but I don't see how you could be well-versed in every kind of problem you're going to encounter." Elizabeth drew on her perception of her capacity for self-directed learning, and said, "I don't think I need like total solid background in all of them . . . once you work on the project you can learn more about that."

In some cases, students simply denied the relevance of certain kinds of context-related knowledge to engineering, altogether; to the work they anticipated doing as professionals; or to engineering education. These students rejected the notion that such knowledge was important for them to know, or deemed it a much lower priority than technical knowledge. Matthew was so strongly opposed to the notion that other disciplines could be sources of relevant knowledge for engineers that he claimed to have trouble even comprehending the question.

> "I mean I'm not real clear on the whole idea of infusing designs with ideas from those disciplines, but assuming for a moment that that actually makes sense, then I would say I'm not prepared for that. . . Uh, the first part does, and then we also . . . The first half, up until— grounded in the basics of mathematics and science, yes, definitely. And who will expand their vision of design through these other things, that doesn't make any sense to me. I mean, okay, economics. . . I could see some application there. . . Although probably not a lot. But humanities and social sciences, I cannot imagine how I would use that in engineering."

Dissecting the NAE statement, Matthew distinguished between those elements that fit with his conception of engineering and those that do not and drew a clear line between what he felt responsible for knowing and what he did not. Nicholas said that the NAE's call to ethically assist the world "sounds kind of socialistic to me." Later he added, "I don't know what I'm supposed to do to assist the world. . . I'm not on some mission to assist the world." Austin was also resistant to the value of context-related knowledge, adding that ". . .to be a more effective engineer, I don't need more humanities, social sciences or economics. I need more, you know, engineering classes."

If they did not outright reject the relevance of the context-related knowledge areas discussed in this study, students narrowly defined knowledge from other disciplines in terms of costs and user needs. To the extent that students acknowledged the broader global, societal, environmental or economic contexts, they argued that there was no way to know what they would face in the future. Students thought it would waste the limited time they had to learn technical knowledge in school now, and that they could pick up contextual knowledge as needed in the future.

For the most part, students said their exposure to context-related knowledge occurred outside the engineering curriculum, rather than in. Some students cited elective courses they had taken outside the department. Other students cited experiences outside higher education that exposed them to context-related knowledge. Elizabeth felt her upbringing in a "third-world country" gave her a unique understanding of the developing country context, and enabled her to consider more contextual issues than many of her peers, "Sometime I see things differently than other people. . ." Likewise, Matthew felt "reasonably comfortable" adapting to global issues, but it was "because I kind of follow the news to some extent, stay aware of world events and all that, what's going on in other parts of the world." Ethan felt well prepared, because, "I read The Economist cover to cover every week."

Electives courses were a promising source of context-related competencies for many students. A few students saw the relevance of electives in humanities and social science in terms of helping them develop creativity and critical thinking skills. For example, Emily's course in ''Indians in Cinema'' was ''good to, you know, have a break from engineering and have your mind work in a different way, I guess, and probably helped me with my creativity and, um, my ability to think of things from a different perspective.'' As indicated in her comment, Emily did not merely come away with an understanding of a particular culture, but with a broader and transferable understanding that opened her mind to different perspectives that she felt would facilitate creativity.

Most students agreed that their engineering instructors did little to expose them to global forces and trends or ethics. It was either ''not really something we talk about a lot'' or covered just ''a little bit.'' For instance, Drew said he had to write an ethics paper for a design course ''but it was BS. . . They [do it] just to fill out all the ABET credits, accreditations.'' Kara felt that school had ''prepared me all right.'' But she was hard pressed to say exactly what actually had been covered. As she described the emphasis on ethics in her senior design class, she admitted, ''It was difficult to get to that point in any of the projects in class where [ethics] was really emphasized. . .'' The intention to cover ethics apparently was conveyed, but never followed through.

Michael gained context-related knowledge ''. . . not from school, just from life, from traveling, talking with people, just reading books on my own. So, it's not a result of my education. Well, yeah, school gets in the way of education.''

> ''I guess with my elective classes they've provided some sort of awareness, I guess. But within engineering, it just seems sort of thrown on last minute these past few quarters, where it's like, oh, you need your ABET accreditation.''

Providing limited or no targeted instruction on context-related knowledge creates conditions that are consistent with engineering students' lack of awareness of and sometimes resistance to such knowledge. Students told the interviewer that if their engineering instructors covered a context-related subject area at all, they did it superficially and solely in the service of ABET accreditation. It is no wonder that students were somewhat stymied by the NAE aspirations for the contextually competent *Engineer of 2020*. To address this issue and identify ways to teach students about context, we turn now to the educational experiences that these students found to be significant in terms of learning.

4.2 Significant learning experiences

The learning experiences that students chose to reflect on covered a wide range of learning milieus. Table 2 contains a short description of these experiences, as well as whether the activity lay within an engineering department, whether it was required for the major, and whether the work was accomplished primarily inside or outside the classroom.

In consideration of space, we will focus our discussion here on the narratives of three students—Kara, Samantha and Austin—whose reflections on significant learning include the qualities and outcomes of significant learning described by students across the larger cohort of 14 out of 15 who chose to answer our questions about significant learning. We selected these students to highlight both the variety of sources for significant learning as well as their rich reflections on those experiences. Although their stories are unique, the qualities and outcomes of significant learning that they identify are present throughout the cohort's stories.

Kara

Kara, a mechanical engineering student, cited her capstone design project as her most significant

Table 2. Significant learning experiences cited by APS students

Pseudonym	Significant learning experience	In engineering department?	Required for major?	Primarily inside classroom?
Austin	Society of Automotive Engineering race car competition (SAE formula)	yes	no	no
Brandon	Design capstone	yes	yes	no
Drew	None discussed	n/a	n/a	n/a
Elizabeth	Introduction to Engineering Design (elective)	yes	no	yes
Emily	Course required for major	yes	yes	yes
Ethan	Design capstone	yes	yes	no
Jesse	Service project abroad for Hillel student organization	no	no	no
John	Dating relationship	n/a	n/a	n/a
Justin	Research project	yes	no	no
Kara	Design capstone	yes	yes	no
Lauren	Course required for major	yes	yes	yes
Matthew	Undergraduate research assistantship	yes	no	no
Michael	Calculus course (prerequisite)	no	yes	yes
Nicholas	Course required for major	yes	yes	yes
Samantha	Undergraduate Scholars in Research Program (USIRP)	yes	no	no

learning experience at LPU. The capstone spanned two academic quarters and involved working on a three-person student team for an actual client, a non-profit organization. Kara described how the team spent the first quarter primarily conducting preliminary research and design and the second quarter doing an actual implementation. For Kara, a primary reason her capstone was significant was because it was a cumulative synthesis and integration of all her engineering knowledge. Kara also described how much self-direction was involved in the capstone and the challenge that accompanied this condition.

> "[I]t incorporated everything that we had learned up until that point, and it was just kind of a—there was no other way to go about it, other than to kind of throw you off the end of the dock and say, "Okay, we've given you all the tools, now go use them."

The metaphor of being "thrown off the end of a dock" brings to mind not only the expectation that the students could be self-directed but also the challenge that exists when this expectation is high. Kara said she incorporated all the engineering knowledge that she had acquired to stay afloat. She continued to reflect on the struggles that she and her teammates had encountered with the project in the second quarter. She said they ran into several unexpected "hurdles" that seemed beyond the scope of what she had previously imagined an engineering project would entail.

> "And I think being one of the important lessons I learned from that experience is that an engineer's job is maybe only 10 percent engineering and the rest of it, perhaps—I don't know, we'll see when I get out into a job, but the rest of it is all of the logistics and the running around and the getting people together and making—or just, you know, keeping people on task and together and so forth. So—and that's the reason that it spilled over into this quarter, was because we just—each one of us [was] responsible for a different section of the project, and all three of us—two of us more than the third person—just kept running into issues."

While engaged in this learning experience, Kara discovered that the work of engineering is only in small part, design. In addition to design, there is the project management work involving logistics, working in teams, and communications. Interestingly, Kara referred to such work as not being engineering. It suggests that perhaps the courses taken up until this point—though they may have required teamwork, project management, and communications skills—did not present these as true elements of engineering practice.

Although Kara says this work is not engineering, we believe that she means to contrast this broader view of the work that engineers do with what she had thought engineering would involve prior to taking the capstone course. For Kara, it was an "important lesson" and she speculated that "when I get out into a job," she would encounter the same conditions. Also, the rest of her narrative indicates that she encountered similar issues in another course. Importantly, such a change in thinking about what engineers do (and therefore what Kara will do) can be identified as transformational in that it has a fundamental impact on how Kara sees herself as an engineer, and she will bring this newly refined professional identity into future engineering contexts.

Kara characterized the design capstone as largely self-directed and the challenge at times frustrating, yet at the same time she reflected upon how "in the end it was good for us," especially with respect to claiming ownership of the experience.

> "[W]e were left to our own devices a lot. We had an advisor, of course, and we met weekly and got a lot of feedback, but she—you know, despite the fact that we would have liked a little more direction, I think that in the end, it was good for us to have that experience of trying to make it on our own and make the decisions by ourselves. Working with other students and working on a single project for so long really gives you a lot of experience."

In sum, Kara found the design capstone, a formal part of her engineering curriculum, to be a significant learning experience worth talking about because it entailed *self-direction* and *knowledge integration*, which she further associated with the substantial *challenges* presented by the project. Kara also associated self-direction with owning the project, thus providing *internal motivation* to succeed. Importantly, she discovered that the work of an engineer is much broader than she had originally thought. Whether she considered this work engineering or not is subject to interpretation, but clearly, she felt that she would be responsible for doing it in the future. The experience entailed a fundamental *transformation* in Kara's thinking about the identity and work of engineers.

Samantha

Samantha's significant learning experience came from participation in a competitive interdisciplinary program in which she was involved LPU. The program, Undergraduate Scholars in Research Program (USIRP), was established through an NSF grant to provide a mechanism for undergraduates to experience and learn how to do laboratory research. Students selected for the program conducted research under the guidance of a faculty member in their lab and received credit for participation. Samantha contrasted this experience with taking a "normal" lab course:

> "I'd probably say the [NSF-sponsored research] program [was the most significant]. I don't know if you

> want to—I guess just because it was the first undergraduate research, I guess, that I did, because my pathobiology lab [course] was more they just told me what to do. So, I went through all the motions, but it wasn't really my ideas or anything. . . [During the research experience] I read a bunch of papers, and then we discussed—like my mentor and I—about what we wanted to do, and then we tried a bunch of things, and like things wouldn't work, so then we have to re-decide what we wanted to do again. It was pretty fun when it worked in the end."

Samantha thought that one factor contributing to the value of this learning experience was that she was able to participate in the planning rather than just being "told what to do." Thus, a central quality of this experience was how it provided an opportunity for internal motivation. Indeed, Samantha's narrative also suggests the experience demanded of her a measure of self-directedness, as she conducted independent secondary research and participated in the emerging research plan, rather than simply following directions. Furthermore, the learning experience contained an element of challenge, in the "bunch of things" Samantha and her mentor tried that "wouldn't work" before they finally found success. It is noteworthy that she discussed how "it was pretty fun when it worked in the end," which suggested to us that the trial and error of research culminated in a rewarding experience.

Another feature contributing to this positive experience was that it was experiential and appeared applicable to other contexts. Samantha described, ". . . it was really hands-on. So, I got to learn by doing things." It was also at this point in her narrative that Samantha described how her *mentor* was a significant factor in her positive experience:

> "Um, I have a good mentor. He's really knowledgeable, so if I have any questions, he usually knows the answer. Yeah, I think it helps learn, 'cause if you—I guess you can learn what kind of things work and what don't, and if they don't work, then what you should do next. I plan to continue doing it through my capstone, so hopefully all the research I've done so far can continue on and be related. And then I also—like I really like what I'm doing, so when I go to graduate school, I think I'm going to look for a similar-type lab."

Mentors can play an important role in significant learning experiences when they act as agents who guide students on a rewarding path. In our interviews, some students acknowledged the value of their teachers/mentors, especially in relation to how these agents facilitated other positive qualities of the learning experience.

To summarize, Samantha described the NSF-funded student research project as a significant learning experience because it provided *internal motivation* by allowing her to fully participate in the decision-making about the research rather than simply following directions and because it required her to be *self-directed*. The trial-and-error flavor of research presented a *challenge* that Samantha found enjoyable. Finally, Samantha noted the important role of her *mentor* in facilitating the other qualities of the significant learning experience.

Austin

In addition to significant learning experiences that came from participation in formal engineering education, some students found co-curricular activities significant. Austin, a mechanical engineering major, cited his experience working on a team to design and build a car for the Formula SAE competition, a design competition developed by the Society of Automotive Engineers in which engineering student teams design and build a prototype of a Formula-type race car.

> "I think working on SAE and with various team projects has been probably the biggest learning experience, just because it's the whole—like you said, if you're trying to get a system to work, you can't build all the parts, you have to call people, and that's been, I don't know, one of the biggest things, like talking to people, asking them about their product and trying to make things, I guess, fit together that way doesn't—I don't know, it seems like it doesn't always work out like you originally had planned. You learn something new. . ."

Austin drew our attention to a number of features of project work that are important for engineers to experience prior to entering the workplace. He described "trying to make things. . .fit together," characterized working with others, coordinating the various contributions to the overall design, as "learning something new"; that is, what we would identify as *knowledge integration*. In addition, Austin discovered from working on his own subsystem that there is a distinction between the "book" context and real-world environments:

> "Yeah, just work with what you get, I guess, and that's—you can't always—basically because, I mean, you can't just kind of take what the book—the book says you should use this part, but if you can't actually find it, then obviously it's a little more difficult to use, and that's kind of been, I guess, just tracking down parts, getting things built, you know, outside of like getting other people to build things for them, it's been definitely a learning experience and something I assume would be useful later on. . ."

Austin concluded that when he couldn't "take what the book says," the process of going beyond the book was also a learning experience. We observe that Austin's description of this learning experience also suggests self-directed learning when you have to "track down parts" or "get things built" and that it was challenging because "the book" did not provide current information and it became "a little more difficult" to accomplish the tasks at hand. Austin also asserted that everything he learned during this experience "I assume would be useful later," indicating an awareness of the applicability of this learning. In further describing the process of ordering parts for the car and integrating all the subsystems, Austin reiterated the transferability of what he was learning in this process.

> ". . . I think stuff like that is pretty applicable to any job. I mean, I guess I haven't really worked, you know, I guess, as an engineer yet, but I mean I'm sure any time you're designing something, just getting it to fit together with the other systems and getting all the parts to meet together is—I mean basically that's what we're doing in SAE, you know, what we've been doing for other class projects, and it's kind of, I don't know, I assume—that's what it sounds like my job is going to be like, so."

Although he had not yet worked as a professional engineer, Austin speculated that his experience with the Formula SAE competition resulted in knowledge and skills that would be *applicable* in the workplace. We believe that this learning experience was *transformational* for Austin the same way Kara's had been for her, in bringing to light a broader range of knowledge and skills that engineers must bring to bear on their practice, than either had originally thought.

Austin found designing and building a car to be a learning experience through which he developed knowledge that was applicable to the real world. The project was complex, involving knowledge integration and surprises along the way that challenged him to deviate from "the book." It required Austin to be self-directed and to transform his conception of engineering work and think more broadly about the context in which engineering is done.

The significant learning experiences described by Kara, Samantha and Austin are representative of the larger set of reflections by the students in the APS study. Students who reflected on significant learning experiences explained that such experiences contained at least some of the following qualities: They (1) were experiential/applicable, (2) involved self-directed learning, (3) involved internal motivation, (4) were exceptionally challenging, and (5) were facilitated by an influential teacher or mentor.

- By *experiential/applicable*, we are referring to experiences that students described as hands-on applications of foundational knowledge in a lab, a research project, or an authentic engineering experience. We also refer to learning experiences that students describe as resulting in knowledge that is applicable to the real world of engineering work. For instance, some students described how their instructors gave real-world examples to connect theory to practice, some students discussed how working in a research lab brought theory to life and some described working on authentic engineering design projects.
- Many students in the APS mentioned learning experiences where they were required to engage in a substantial amount of *self-directed learning;* that is, directing and managing their own learning.
- *Internal motivation* is a feature of significant learning experiences where students arrived at the experience with an existing personal or professional interest in the topic or developed an interest as a result of the experience. A couple of students noted that having some say in what they were going to be doing was a motivator for learning.
- Students often described learning experiences that were exceptionally *challenging* in one way or another, where even frustrations and obstacles to completing a project were considered factors in why the learning experience was significant for the student. Students also recounted how they had not necessarily appreciated the challenge at the time but in retrospect found it to be a factor in why the learning experience was powerful for them.
- Some students described *teachers and mentors* whom they had encountered over the trajectory of their engineering education, who encouraged their interests and abilities, and who facilitated some of the aforementioned qualities of significant learning experiences.

Students described significant learning outcomes in terms of (1) knowledge integration and systems thinking, and (2) transformation.

- Sometimes a student described a profound change in their worldview; that is, thinking differently about themselves, engineering, and the world. We refer to this significant learning outcome as *transformation*.
- Over the course of the interviews, students recounted difficulties comprehending abstract theories presented in some prerequisite courses (e.g., physics). However, many identified learning experiences as being significant when they were able to comprehend holistically how these various abstract processes and theories were integrated and related to one another, related to engineering work, and to the broader context in which engineering is done. Also, some students were influenced by group projects where they were able to see how their particular work related to others'. We refer to this significant learning outcome as *knowledge integration* and *systems thinking*.

APS student narratives corresponded to Fink's model of significant learning where the goal of instructional design is to create an experience in which students are engaged, their efforts result in significant and lasting learning, and the learning adds value to their lives beyond the classroom [7, 8]. Students described experiences that interested, challenged, and motivated them. These experiences required students to become actively involved in the learning process, to apply what they learned to authentic projects, and to be self-directed. The learning they gained in some instances broadened or transformed the way they understood engineering and themselves as engineers, and many observed that this new awareness was likely to serve them in the future.

Fink argued that if a course was geared toward significant and lasting learning, student engagement and value of the learned products were likely to follow. Fink also argued that learning outcomes should go beyond foundational knowledge to include learning how to apply that knowledge, how it is integrated with other knowledge, and being further prepared to learn more in the future [7–8]. From the APS students' narratives and following Fink, we believe that significant learning can occur in classrooms; indeed, it can be designed into the classroom learning experience. We turn now to a learning activity that has been incorporated into three engineering design seminars and two sections of a required course in Professional Teamwork and Communication Skills taught by one of the authors. This example demonstrates how significant learning experiences can be designed for the classroom.

4.3 Significant learning in the classroom to promote thinking more broadly about context

In this section, we will discuss an assignment that was designed to engage students in thinking about the concept of perspective and how it can be incorporated into engineering design. The "Perspective and Art" assignment has been included in three design seminars and two offerings of a required course in Professional Teamwork and Communication Skills taught by one of the authors for majors in Human-Centered Design & Engineering (HCDE) at LPU between 2013 and 2017. A learning outcome for this assignment is to "articulate [a] definition of individual perspective . . ." [10]. The activity focuses students' attention on their own perspectives as designers as well as the many unique perspectives that other stakeholders bring to a designed product. A larger goal of this and other related learning activities is to encourage students to think about the broader contexts of engineering design.

The assignment is designed with significant learning in mind. In particular, it is experiential, self-directed, intended to connect with students' own interests, and challenges students to think about a set of concepts they take for granted or have not perceived prior to participation in the assignment. The learning outcomes include recognition of the larger systems in which engineering design is situated and possible perspective transformation.

In this particular assignment, students are asked to engage with the concept of perspective or point of view. To inspire their definitions, the educator provides the following vignette that David Foster Wallace uses in his book "This Is Water",

> "There are these two young fish swimming along and they happen to meet an older fish swimming the other way, who nods at them and says, 'Morning, boys. How's the water?' And the two young fish swim on for a bit, and then eventually one of them looks over at the other and goes, "What the hell is water?" [35, p. 1]

This vignette explores the idea that elements of our everyday worlds are invisible to us unless we look for them specifically. Perspectives and the various contexts—for example, global, social, environmental, economic, cultural—in which they are cultivated, may go largely unobserved unless students are asked to examine them. For the assignment, students are tasked to find three pieces of art of various media and analyze them with respect to the concept of perspective. Students are then asked to reflect on their own experiences with the concept of perspective, connect that to the insights that they gained by finding the artwork, and write a piece on how these experiences relate to their profession (which is broadly described as user experience designers or researchers). The wording of the homework assignment is presented in Fig. 1. This homework assignment is followed by an in-class presentation where each student presents one of the three pieces of art that they have identified and describes it to the rest of the class. Through the presentations and class discussions, the students experience first-hand that there are a wide variety of perspectives on the concept of perspective, itself.

The assignment is intended to be a significant learning experience for the students. Being free to choose their own path to understanding the concept of perspective, students demonstrated that the "Perspective and Art" assignment inspires *internal motivation*. Consider the diverse examples of art selected by students for a design seminar, as shown in Fig. 2. The first example shown in Fig. 2 is a piece of music by Mozart that may be played both right side-up and upside-down. The second example shown is a sculpture that looks quite different depending upon where the viewer is standing in relation to the art. The third example is a cartoon panel. All reflect the personal interests of

Perspective and Art Assignment

1. Find three pieces of art that represent perspective to you.
   - Choose the three pieces from at least two categories of art.
   - Think of art broadly (visual art, music, dance, poetry, prose, graphics, craft, videos, movies, photography, etc.). *Be sure to include citations for the three art pieces you include.*
   - Briefly describe why each one represents "perspective/point of view" to you.
   - Choose **one** of your three pieces of art that you want to present to the class.
2. Reflect on your experience with the concept of "perspective/point of view" and the three pieces of art that you chose for this assignment and relate that to the UX/user research profession. Write a paragraph or two.

Fig. 1. "Perspective and Art" homework assignment.

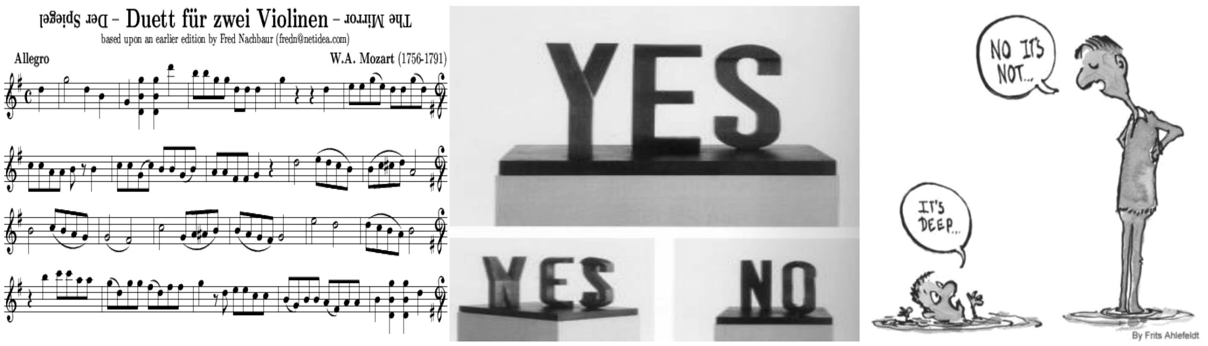

Fig. 2. Specific examples of art collected by students engaged in the Perspective and Art assignment.

the student who presented them to the class. Another student in a design seminar introduced a painting, "This is perhaps my favorite piece of art." The variety of art that students brought to the assignment and the way students talked about that art suggests they found art that spoke to their own unique interests and life experiences.

The activity also involves *self-directed learning*, with students given a free hand to select art that is meaningful and interesting to them. In each of the five instances this assignment has been used, students have responded with wide-ranging examples of art. An indication of the range of art genres that students bring to this activity is shown in Table 3. In a course on Professional Teamwork and Communication Skills, students selected one of their three chosen artworks to discuss in class. As shown in the table, in a class of 22 students who completed the assignment, nearly as many art genres as students were represented in class.

In the same Professional Teamwork and Communication Skills class, students responded to a survey instrument developed by the Consortium to Promote Reflection in Engineering Education (CPREE) that included a set of closed-ended questions along with several open-ended questions [36]. When asked what they took away from the assignment, one student observed, ". . . some people chose art pieces because of the authors, and some people chose them because of the meaning of the art that

Table 3. Art Genres Selected for Perspective Assignment

Art genre	Number of instances
Comic illustration	1
Dance	1
Feature-length film	1
Illustration	1
Image Projection on moving objects	1
Map	2
Music video	2
Painting on architectural elements	3
Photograph	1
Poster	1
Sculpture	3
Song lyrics	1
Television program episode	1
Video game	1
Written word—novel	1
Written word with illustration	1

they comprehend . . .'' indicating students' varied interests were being met by the assignment. Another student agreed, ''[T]he fact that everyone shared a completely different piece of work also shows that perspective means something different to each person. . .'' Several students wrote that they liked hearing about others' chosen artwork. As one noted, ''I really enjoyed being able to see what other art pieces my peers are interested in.''

Although the ''Perspective and Art'' assignment is not an actual engineering design experience, several students found it to be applicable to engineering design. One student reflected, ''In this world there are so many different perspectives and HCDE [human-centered design & engineering] is all about understanding the perspectives as much as we can . . .'' Another wrote that they learned, ''various people have different perspectives in art and that empathy is critical for a UX designer . . .'' Problem scoping is an important aspect of engineering design and acknowledging multiple stakeholder perspectives is an important element of problem scoping. One student explained, ''Perspective plays a large part in design. Figuring out how you are approaching a new problem space (from what lens, with what intended affect) will change how your overall design operates.''

While the assignment was not challenging in a traditional way for an engineering course, some students reflected that examining perspective itself is difficult. One student wrote, ''Perspective is something that is easily found, as everything that has ever been made carries with it the perspective of the designer or artist. Intentionally looking for perspective is a bit more challenging . . .'' Another student noted that it is important to seek perspective, ''but not always easy.''

In addition to their remarks on the qualities of self-direction, internal motivation, applicability, and challenge inherent in the assignment, students also looked outward, beyond the activity itself. Fig. 3 contains the results of a series of closed-ended survey questions that students in the Professional Teamwork and Communication Skills course

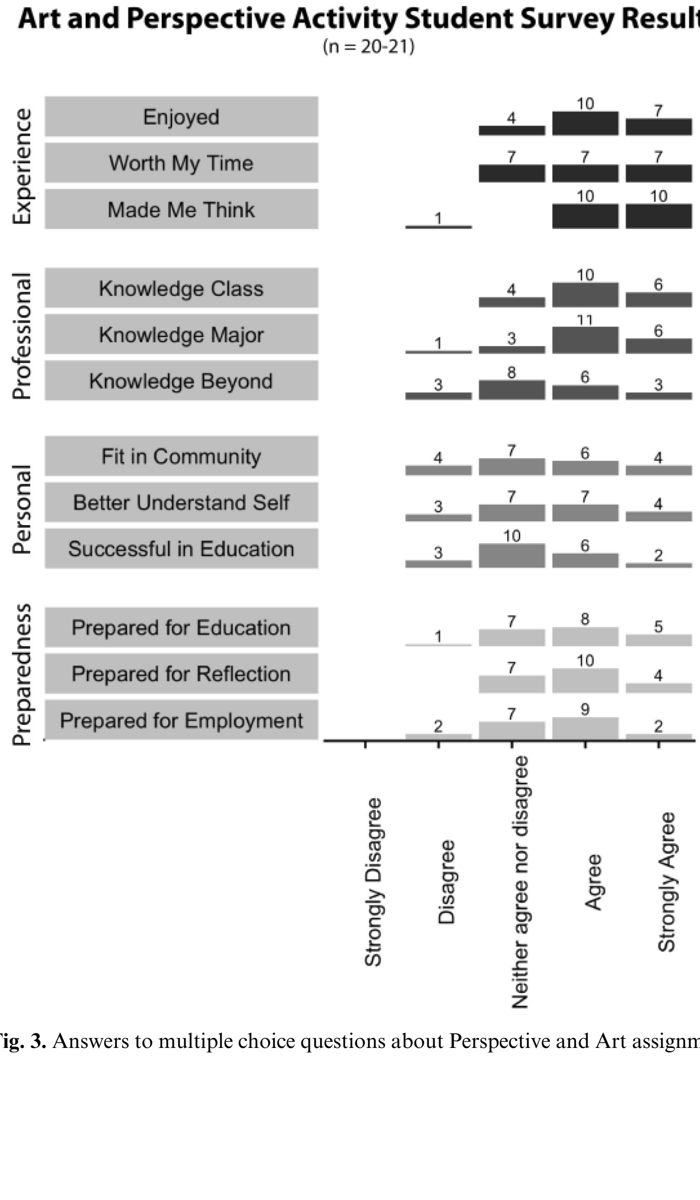

Fig. 3. Answers to multiple choice questions about Perspective and Art assignment.

answered about the "Perspective and Art" assignment. Students were asked to indicate their level of agreement with a series of statements including, "I enjoyed this reflection activity," "The reflection activity was worth my time," and 10 additional statements beginning with "The reflection activity helped me to. . ." [36].

Figure 3 shows the counts of students by level of agreement with a statement (note: not all students answered all survey questions). The statements are organized into four categories. "Experience" statements refer to the students' experience of the assignment itself: Did they enjoy it? Was it worth the time? Did it make them think? "Knowledge" statements refer to the kind of knowledge that students gained from the activity: learning related to the class in which the assignment took place, learning related to the student's major, and learning beyond the class and student's major. "Identity" statements refer to any potential connection between the assignment and the student's sense of self: fit with the campus community, understanding of themselves, and seeing themselves as people who can be successful in their education. "Prepare" statements refer to the link between the assignment and preparation for other elements of the student's life: preparation to do well in education, preparation to use reflection in the future, and preparation for future employment.

Our findings suggest that the assignment encouraged learning outcomes characterized by *knowledge integration* and *transformation*. Students were mostly in agreement with or neutral about all the statements as shown in Fig. 3. Many students agreed or strongly agreed that the assignment helped them learn something that would be relevant to the class, their major and beyond, suggesting that students recognized the value of integrating this knowledge with other skills and knowledge. As one student wrote, "This helped put my major in perspective!"

Similarly, many students agreed or strongly agreed that the assignment helped them learn something about themselves and how they fit into the larger campus community: "[I]nstead of just 'thinking' about these topics and scratching the surface, I was able to dive deeper in the context of my life and relate these concepts to other forms of expression in art." A student explained how important this new way of looking at things was to the design process: "Understand someone else's perspective and realize that yours is not the only one or the most important one, this has to be done throughout the design process. Think outside yourself."

Many students commented on the differences between their own perspective and that of others, as one wrote, "I think it is rather interesting to see different people looking at the same art and yet understand it in a completely different way that I am." Similarly, students often commented on the different tastes and artistic choices that others made, "I really enjoyed being able to see what other art pieces my peers are interested in." It is possible that students who never gave the concept of perspective much thought, now found the variety of perspectives in the world difficult to avoid.

Students wrote that the "Perspective and Art" assignment did have qualities of significant learning. It had a strong element of self-directed learning, inspired internal motivation, and students found that the knowledge they acquired in the assignment was applicable to the class, their majors, and beyond. There was an element of challenge in that students were asked to examine perspective, something that had largely been invisible for many of them prior to participating in the assignment. Did the assignment result in significant learning? Students responded in the affirmative. Students said that their new understanding of perspective would add value to their further learning and participation in engineering design. In some cases, they also discussed how bringing perspective into clarity was enjoyable, interesting, and changed the way they approached design.

5. Conclusion

We began our discussion in this paper with conversations we had with students a decade ago, in which they took a rather limited view of the context of engineering design. At the same time, these students pointed us in a promising direction where significant learning experiences engage students, result in lasting and meaningful learning, and add value to students' lives beyond the classroom. Students provided a recipe for significant learning containing one or more of the following ingredients:

- Experiential, hands-on, authentic learning.
- A strong element of self-direction.
- Internally motivated, speaking to the interests of the student.
- Especially challenging.
- Facilitated by an influential teacher or mentor.

The results of such an experience could include thinking more broadly about engineering by integrating knowledge, situating it within a real-world context of engineering work, and thinking beyond the immediate context to include multiple stakeholders and multiple contexts. One of the authors has employed this recipe many times in the years that have followed, incorporating several carefully designed assignments in engineering curriculum. We concluded our analysis here by describing one of those concrete efforts—the "Perspective and Art" assignment—to create a significant learning experience in support of considering the broad context of engineering design. Our examination showed that this particular assignment did promote significant learning outcomes, including those identified by students a decade ago. For many engineering students, seeing perspective, itself, is a new experience and broadens the way they view engineering design. The next task for educators, we believe, would be to engage students in further assignments in which they examine more deeply the global, societal, cultural, environmental, and economic contexts in which perspective is formed.

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